

E X P E R I M E N T S

ON THE

A N A L Y S I S

OF THE

H E A V Y I N F L A M M A B L E A I R.

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From the PHILOSOPHICAL TRANSACTIONS.



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## E X P E R I M E N T S, &c.

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**I**N a Paper read before the Royal Society in the year 1788, I suggested an idea, that the heavy inflammable air is a compound of the light inflammable and phlogisticated airs. At that time I had observed, that the heavy inflammable air, or at least fixed air, is formed upon the decomposition of nitrous ammoniac by heating it in close vessels; and that this air is affected by the electrical shock, like other elastic fluids into whose composition the light inflammable air enters. The conclusion which I then drew from those facts seems to be supported by several subsequent experiments, which I now take the liberty of laying before the Royal Society. Should it hereafter be found, that the real constitution of the heavy inflammable air differs from what I conceive to be the result of the facts below recited, the facts themselves may still have their use, as they exhibit several properties hitherto unobserved of the most extensive compound body we know, excepting water.

Several elastic fluids containing the light inflammable air, as the hepatic and alkaline airs, being decomposed by the electric spark, I was induced to try it on the heavy inflammable

air, as soon as I suspected that it contained the lighter air as a constituent part. Agreeably to my expectation, this experiment immediately detected the light inflammable air; for such an expansion took place as could not arise from any other known substance. Thus the heavy inflammable air was sometimes expanded to twice its original volume; and yet, upon examining the air so expanded, not a sixth part of the whole was found to have undergone a decomposition: for instance, when two measures and three quarters were expanded to six, it appeared by experiment, that nearly two measures and a half remained in their original state.

After the inflammable air has been expanded to about double its original bulk, I do not find that it increases further by continuing the shocks. Conceiving that the progress of the decomposition was impeded by the mixture of the other airs with the heavy inflammable, I passed the spark through a mixture of the heavy inflammable air and of the light inflammable air, obtained from diluted vitriolic acid and iron filings; but the expansion succeeded nearly as well as when the heavy inflammable was electrified alone. This is an almost insurmountable obstacle to this mode of investigation: yet it has such advantages in other respects, the air to be analysed being unmixed with other substances, and only in contact with the glass and quicksilver by which it is confined, that I determined to prosecute the subject in this manner as well as I could.

From this partial decomposition of the heavy inflammable air we obtain a mixture of the two inflammable airs with phlogisticated air; that is, of the heavy inflammable air not decomposed, of the light inflammable air disengaged by the spark, and of phlogisticated air. How much of this phlogisticated air pre-existed in the heavy inflammable air, and how much

much was disengaged during the operation, it is not easy to determine. Neither are we acquainted with any substance which will separate the two kinds of inflammable air by combining with the one and leaving the other: but we know that dephlogisticated air will combine, in certain proportions, with each of them, either mixed or separate; that with one of them it forms fixed air, with the other water. Therefore, by inflaming dephlogisticated air with a mixture of these two airs, and observing the quantity of dephlogisticated air consumed, and the quantity of fixed air produced, we discover the excess of dephlogisticated air consumed above what is sufficient for the production of the fixed air; and may conclude, that this excess of dephlogisticated air has combined with light inflammable air. This conclusion is further confirmed by attending carefully to the contraction which takes place upon inflaming these airs, which is much greater in proportion to the quantity of fixed air produced, when a mixture of the two inflammable airs is inflamed, than when the heavy inflammable air is burnt alone. It is well known, that in all experiments of this kind, what remains after the combustion of the airs mixed together in due proportion, and after the separation of the fixed air, is chiefly phlogisticated air. From a considerable number of experiments, conducted with great care and attention to all these circumstances, I have endeavoured to approximate to the quantities of the phlogisticated and light inflammable airs disengaged, when a given quantity of the heavy inflammable air was decomposed. But all that can be attained to, is only an approximation to truth. The quantity of air decomposed by this method is so small, and the separation of the different parts into which it is resolved is attended with such difficulties,

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that an accurate analysis of the heavy inflammable air can never be obtained in this manner.

I therefore attempted to decompose the heavy inflammable air by means of sulphur, which readily unites with the light inflammable air in a condensed state, and with it forms hepatic air. Having introduced some sulphur into a retort, filled with heavy inflammable air, and applied a sufficient heat to melt and sublime it, I found, that a considerable quantity of hepatic air was formed. After this air was absorbed by water, I could not perceive that the remaining air differed from the heavy inflammable air before the operation. Sulphur mixed with powdered charcoal, upon being heated, yields hepatic air in great abundance, almost the whole of which is absorbed by water. The small unabsoed residue, which does not exceed a hundredth part of the bulk of the whole air, appears to be phlogisticated air.

In whatever manner the heavy inflammable air was decomposed, whether by passing the electrical spark through it, by melting sulphur in it, or by heating sulphur and charcoal together, an appearance constantly occurred, which seemed to indicate, that volatile alkali is formed, whenever the heavy inflammable air is decomposed. The circumstance is this: a small piece of paper, stained with any blue vegetable substance, is turned green by standing in the air during any of these processes; and this green is changed to red upon the addition of an acid. The inflammable air had been very long exposed to water, and had no such effect upon blue vegetable substances before the operation.

I have concluded these analytic attempts with several observations on the formation of fixed air from some substances, which consist only of the light inflammable, phlogisticated, and dephlogisticated airs, and from others, in which these three  
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airs are combined with such matters as cannot be suspected of having any place in the composition of fixed air.

I proceed now to a detail of the experiments, upon which these observations are founded.

Exp. 1. A bent glass tube, one-third of an inch in diameter, open at both ends, being filled with, and inverted in quicksilver,  $2\frac{4}{5}$  measures of heavy inflammable air were thrown into it, and electrical shocks were passed through this air till it measured  $4\frac{1}{2}$ .

Lime water being then thrown up to it was not rendered in the least degree turbid.

During the operation a thin deposit, of a whitish or ash colour, appeared upon the inside of the glass tube and quicksilver. This was a common appearance, for which I can give no reason.

The measure, made use of in this and in all the following experiments, is  $\frac{1}{4}$  of an inch. The air being thrown into the tube, the length of the column of air was measured by a moveable scale thus graduated. Some objection may be made to so small a measure; but it is really unavoidable on this occasion, on account of the great difficulty of decomposing the heavy inflammable air in larger quantities. I attempted it upon a larger scale in a jar perforated with brass rods, such as is used for inflaming airs; but after having worked for many hours, in passing electrical shocks through air confined in one of these jars, it was not expanded more than one quarter of its original bulk. A piece of paper, coloured with a blue vegetable substance, was turned green by standing in the air during this operation.

It was a very tedious work to throw airs into the small tube in such quantities as could be expressed in integer numbers of the

the measure : I have therefore generally been contented to use fractional numbers, and have been studious only to introduce such quantities of the airs as were convenient for the experiments.

The inflammable air used in all these experiments was obtained from foliated tartar. I have also passed electric sparks through inflammable air from pit-coal, and found that it expanded in the same manner. Dr. HIGGINS \* has shewn, that 5,5 of inflammable air from foliated tartar inflamed with 7,5 of dephlogisticated air, form 5 measures of fixed air. Dr. PRIESTLEY † has deduced nearly the same proportions of the dephlogisticated and fixed airs, by combining the dephlogisticated and inflammable airs in a condensed state. In the following combustions of these airs, after accounting for the phlogisticated air in the residues, the quantity of fixed air produced seems to be equal in bulk to the inflammable air combined ; and the dephlogisticated air to be to the fixed air, or to the inflammable, in the ratio of 7 to 5 ; or, in other words, when 5 measures of fixed air are formed, it appears, that very nearly 5 of inflammable air and 7 of dephlogisticated air have disappeared. But in burning different airs there will be constant variations in the results, arising from the very different states of the heavy inflammable air ; and therefore, in these observations, I am obliged to follow the proportions which took place in my own experiments.

Exp. 2. Three measures and one-third of inflammable air were expanded to  $5\frac{1}{2}$  : the difference is  $2\frac{1}{6}$ . To this air were added  $3\frac{1}{2}$  measures of dephlogisticated air, which increased the column of air to 9 measures. One electrical spark reduced them to 4.

\* HIGGINS on Acetous Acid, p. 288, 289.

† PRIESTLEY, Vol. VI. p. 27.

Lime water being then thrown up left only three measures of air. A solution of liver of sulphur did not reduce it further. The remaining air inflamed upon being brought near a candle in the open air.

In order to account for this, it must be observed, that, before the inflammation, the airs occupied the space of 9 measures, and were reduced by combustion and lime water to 3. The contraction is 6 measures. Of these the measure of fixed air accounts for 2,4, allowing 1 measure of inflammable air and 1,4 of dephlogisticated air to produce 1 measure of fixed air, according to the proportion stated in the last page; 2,4 measures, which thus went to form fixed air, being taken from 6, which is the whole contraction, leave 3,6. If we suppose this contraction of 3,6 to have arisen from the union of the light inflammable and dephlogisticated air, very nearly 2,4 measures of the former must have combined with 1,2 of the latter. This explains, with a tolerable degree of exactness, both the contraction which takes place, the residue after combustion, and the quantity of dephlogisticated air combined. For without any expansion, the residue from  $3\frac{1}{2}$  measures of inflammable air and  $3\frac{1}{2}$  of dephlogisticated air, after forming 1 measure of fixed air, would be  $4,4\frac{1}{3}$ , which exceeds the residue in the experiment by  $1,4\frac{1}{3}$ . Some dephlogisticated air must therefore be combined, besides what enters into the fixed air: and with what other substance but the light inflammable air could it combine, so as to occasion a contraction of 3,6 measures?

The dephlogisticated air being in this instance insufficient to saturate the inflammable airs, it could not be ascertained how much of the heavy inflammable air was decomposed, and how much remained in its original state. The two following experiments were therefore made in order to determine, in what

proportion the dephlogisticated air is sufficient to saturate this inflammable air, and what quantity of fixed air they produce when inflamed.

Exp. 3. In a large exploding jar I mixed  $4\frac{3}{4}$  measures of heavy inflammable air with  $7\frac{1}{4}$  of dephlogisticated air. After explosion these airs measured something more than  $6\frac{1}{2}$ , and were reduced by lime water to rather less than  $2\frac{1}{2}$ . In this residuary air a candle burnt with an increased flame, as in dephlogisticated air.

Thus very nearly 4 measures of fixed air were produced from  $4\frac{3}{4}$  of heavy inflammable air.

Exp. 4. Into the small bent tube, which was employed in the first and second experiments, I introduced  $3\frac{2}{3}$  measures of inflammable air, and  $5\frac{2}{3}$  of dephlogisticated air. These were reduced by inflammation to  $5\frac{1}{3}$ , and by lime water to  $2\frac{1}{3}$ .

In this experiment, 3 measures of fixed air were produced from  $3\frac{2}{3}$  of inflammable air.

In the third experiment, the quantity of fixed air produced is 4 measures very nearly. The residuary air is rather less than  $2\frac{1}{2}$ . If to  $2\frac{1}{2}$  we add a quantity of inflammable air equal to the bulk of fixed air, that is, very nearly 4 measures, it will amount to  $6\frac{1}{3}$  full measure; and if we further add 5,6, which is the quantity of dephlogisticated air necessary to form 4 measures of fixed air, we shall have  $11,93$ , which is within seven hundredths of a measure of the original quantity of the two airs.

In the fourth experiment, 3 measures of fixed air are produced, which require 3 of inflammable air, and 4,2 of dephlogisticated air; these, added to the  $2\frac{1}{3}$  measures of residuary air amount to  $9,53$ , which is two-tenths of a measure more than the original quantity.

It appears from these observations, that the proportion of dephlogisticated and inflammable air, in the constitution of fixed air, above stated, agrees very nearly with experiment. In one instance, the quantity arising from calculating after this proportion exceeds the real quantity by two-tenths of a measure; and in the other, it falls short of it by seven hundredths of a measure.

It is evident, that  $3\frac{2}{3}$  measures of this inflammable air burnt in the small tube are capable of forming 3 of fixed air. The fixed air, produced by inflaming the same airs in the large jar, bears rather a greater proportion to the inflammable air employed; for  $4\frac{3}{4}$  measures of it produced almost 4 of fixed air. I tried many experiments on these airs mixed together in different proportions, and only in one instance found the product of inflammable air greater in proportion than 4 from  $4\frac{3}{4}$ ; which I therefore conceive to be as much as this air is capable of producing, and suspect, that a small error must have been committed in that instance, which gave a greater proportion of fixed air. The  $\frac{1}{4}$  of a measure which remain, are chiefly phlogisticated air, mixed perhaps with a very small quantity of inflammable air; as will appear from the residues in some of the following experiments, which contain about that quantity of phlogisticated air more than they could derive from the dephlogisticated air. Thus, for instance, in the third experiment, the residuary air measures  $2\frac{1}{2}$ , the quantity of dephlogisticated air engaged in forming the fixed air is 5,6, which added together make 8,1; but the whole dephlogisticated air amounts only to 7,25; the difference 0,85 is nearly equal to the phlogisticated air, which I suppose to have been mixed with the heavy inflammable air.

Exp. 5. Three measures of inflammable air were expanded to  $6\frac{1}{4}$ , then  $4\frac{3}{4}$  of dephlogisticated air were added; after

inflammation they measured  $4\frac{1}{4}$ ; lime water contracted them to  $2\frac{1}{2}$ .

In this experiment  $2\frac{1}{4}$  measures of fixed air were formed, which is nearly 0,28 less than the inflammable air used in this experiment is capable of producing. We have therefore only 0,28 to account for the expansion; and we cannot say, that the whole of this was decomposed, as the dephlogisticated air, even in this experiment, was not quite sufficient to saturate the two kinds of inflammable air; and therefore a small quantity of heavy inflammable air might remain in the residue in its original state.

Exp. 6. A quantity of heavy inflammable air, which measured between  $3\frac{1}{4}$  and  $3\frac{1}{2}$ , was expanded by about 300 electrical shocks to  $6\frac{1}{2}$  full measure. To these were added  $5\frac{1}{4}$  of dephlogisticated air. After inflammation they measured  $4\frac{1}{4}$ , and were reduced by lime water to  $1\frac{5}{6}$ .

The inflammable air in this experiment was between  $3\frac{1}{4}$  and  $3\frac{1}{2}$ ; we will therefore take 3,29, the arithmetical mean of those numbers. The quantity of fixed air produced is less by 0,36 than could be produced from the same airs without electrifying.

It is probable, that a small quantity of the heavy inflammable air may escape unaltered in each of these experiments; the following were therefore made with a still greater proportion of dephlogisticated air, and the residues were examined with more attention.

All the preceding experiments were made with the same airs; these being exhausted, a fresh supply was procured for those which follow. The purity of this dephlogisticated air was such, that one measure of it being mixed with  $1\frac{1}{4}$  of nitrous air was reduced to 0,2 of a measure. The inflammable air was less pure than the former. In the two following experiments

experiments 4,44 measures of fixed air were produced from 5,58 of the heavy inflammable; the remaining 1,18 must have been chiefly phlogisticated air.

Exp. 7. Inflammable air  $2\frac{1}{4}$  and dephlogisticated air 4,58 were inflamed in the small tube. They then measured  $4\frac{1}{4}$ , and were reduced by lime water to  $2\frac{1}{6}$ . After several bubbles of nitrous air, the residue was less than 2 by nearly  $\frac{1}{4}$ .

In this experiment 2,09 measures of fixed air were produced.

Exp. 8. In a large exploding jar,  $2\frac{5}{6}$  measures of inflammable air, and 4,17 of dephlogisticated air, were reduced by combustion to 4, nearly, and then by lime water to 1,75. About a measure of nitrous air being then thrown up, the residuary air measured 1,5.

The quantity of fixed air produced in this instance is 2,35.

Exp. 9. Inflammable air  $2\frac{5}{6}$  measures were expanded by about 200 electrical shocks to 5 and not quite  $\frac{1}{6}$  more. To the air thus expanded, I added as much dephlogisticated air as increased the column of air to  $9\frac{1}{2}$ ; thus the dephlogisticated air was rather more than 4,09. After combustion, they measured fully 4; and, after being exposed to lime-water, rather less than 2. Nitrous air occasioned a small contraction further.

According to the proportion stated in p. 56.  $2\frac{5}{6}$  measures of this inflammable air contain 0,58 of phlogisticated air; 0,58 added to 2, which went to form fixed air, amount to 2,58. But the original quantity of inflammable air, viz.  $2\frac{5}{6}$  exceeds 2,58 by 0,25. What becomes of the 0,25 measures of inflammable air which thus disappear? I apprehend they must have undergone a decomposition, and have been expanded to 10 times their original bulk.

The dephlogisticated air was still further increased in the following experiment.

Exp.

Exp. 10. Three measures of inflammable air, after 150 electrical shocks, became 5,1. To this was added as much dephlogisticated air as increased the column of air to  $10\frac{5}{6}$ . After inflammation it measured about 4,9; and was reduced by lime water to  $2\frac{1}{4}$ . This residue was not inflammable.

The contraction upon burning these airs was 5,93; and the quantity of fixed air appears to be 2,15. This fixed air requires 2,15 measures of inflammable air and 3,01 of dephlogisticated air. These deducted from the sum of the contraction leave 2,92, above what is sufficient to account for the fixed air produced. Supposing this contraction to have been occasioned by the union of light inflammable and dephlogisticated air, 1,94 of the former must have combined with 0,97 of the latter. It is evident, that the quantity of dephlogisticated air used in this experiment is more than sufficient to combine with both kinds of inflammable air.

The fixed air produced in these experiments is 0,23 less in proportion, than was produced, when the inflammable air was not decomposed in the seventh and eighth experiments. It appears by calculation, that these 0,23 were expanded to about ten times their bulk. It is observable, that the expansion in this case is 2,33; and that the quantity of light inflammable air which combined with the dephlogisticated air, is only 1,97, which is 0,40 less. This proves, that it is very difficult, if not impossible, to unite the whole of these airs; and that a small quantity will remain diffused in the residue, unless the airs be much purer than I have been able to procure them; yet it is not probable, that so large a proportion of light inflammable air as 0,40 should escape combustion, over and above what escapes in similar circumstances, when no light inflammable air is present. The addition of light inflammable air

air to a mixture of the other airs would rather contribute to render the combustion more general, and the residue consequently less; for in all combustions, the union of the inflammable and dephlogisticated airs is more complete, as the proportion of phlogisticated air mixed with them is lessened. In general, when air does not burn in such circumstances, we presume, that it is phlogisticated air; and upon this principle we must conclude, that a considerable part of those 0,40 was phlogisticated air.

I proceeded to repeat this experiment with a fresh supply of the two airs; but the tube bursting in the last explosion, a smaller one was used in exp. 12, which however could not affect the result of the experiment.

Exp. 11. Four measures and a half of inflammable air and  $6\frac{1}{2}$  of dephlogisticated were reduced by inflammation to  $5\frac{1}{2}$ ; and by caustic alkali to 2 and a very little more. The remainder was not inflammable.

The product of fixed air is  $3\frac{1}{2}$  measures.

Exp. 12. Two measures and three quarters of inflammable air were expanded to 0.; then, to reduce the column of air, one measure of dephlogisticated air was added, and the electrical spark was passed through the two airs; afterwards 2 measures of dephlogisticated air were added, and the electrical spark again passed through them; and, lastly, 3,59 measures of dephlogisticated air were thrown up, and the electrical spark repeatedly passed through this mixture of airs. After these explosions the airs measured  $5\frac{2}{3}$ , and after the addition of caustic alkali 3,83.

The product of fixed air is 1,83; which is 0,30 less in proportion, than was produced in exp. 11. from the same inflammable air not electrified.

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Notwithstanding the utmost attention, we are liable to a small error in each of these experiments; and there is consequently a small variation in the results; but, I think, they concur sufficiently to justify the following conclusions.

1. That the heavy inflammable air contains the light inflammable air in great abundance.

I apprehend this light inflammable air was, before the application of the electrical spark, a constituent part of the heavy inflammable air; because, if it were contained in the heavier air not as a constituent part, what should hinder its being burnt when the heavy inflammable air is burnt? Can it be supposed, that the heavy inflammable air should contain the light inflammable air in circumstances of combustion, and that the light inflammable air should escape the fire? And if the lighter air be burnt, the same quantity of dephlogisticated air would be necessary to saturate it before as after its being electrified. But it is evident from the preceding experiments, that much more dephlogisticated air is necessary to saturate the air, after it has been expanded by the electrical shock, than before.

2. That no fixed air is formed during the separation of the lighter air from the heavy inflammable air.

Here it should be observed, that if the constitution of the heavy inflammable air depended on an union of the light inflammable and fixed airs, as some have supposed, we should certainly discover the fixed air, when the other part was separated from it. Or, should it be conjectured, that the light inflammable air is separated from water suspended in the heavy inflammable air, in that case, would not fixed air be formed from the other constituent part of the water uniting with the heavy

heavy inflammable air in consequence of the repeated electrical shocks?

3. That the electrical shock separated a substance from the heavy inflammable air, which has some leading characters of an alkali.

When inflammable air is decomposed by sulphur, or when hepatic air is made from charcoal and sulphur, we have the same appearance of an alkali. That this is the volatile alkali is evident from its evaporation, when hepatic air is made from sulphur and charcoal.

4. That the heavy inflammable air, through which the spark has been repeatedly passed, when burnt with any proportion of dephlogisticated air, does not produce so much fixed air, as the same quantity of inflammable air not electrified.

Hence it is evident, that a part of the air is actually decomposed by the spark. Hence also we may infer, that the decomposed air is not resolved into light inflammable air and charcoal, of which some chemists have supposed it to consist, because the charcoal would combine with dephlogisticated air after its separation from light inflammable air, and we should not have such a defect of fixed air..

6. That the residues, after inflaming the decomposed air, are generally greater than those from the air in its natural state, or than can be accounted for from the mixture of the heavy inflammable and dephlogisticated airs.

This affords a strong presumption, that phlogisticated air is extricated from the decomposed heavy inflammable air in a separate state, besides what enters into the volatile alkali, which is formed at the same time. If light inflammable air only were disengaged during the decomposition, the residues would certainly not be greater after inflammation with a suffi-

cient quantity of dephlogisticated air; on the contrary, if the inflammable air were increased in proportion in the mixture, the combustion would be more complete, and the residues less.

Having observed, that sulphur readily combines with light inflammable air, if presented to each other at the instant that the inflammable air is detached from other bodies, before its particles have receded from each other, and that hepatic air is generally formed in this manner, I introduced some sulphur and heavy inflammable air into a glass retort, first filled with, and inverted in quicksilver, and applied a sufficient heat to melt it. The heat was continued till the sulphur was sublimed. The melted sulphur soon acquired a dark reddish colour; as it sublimed, it became quite black, and every part of the retort was covered with a black crust. On the depending part of the retort, where the melted sulphur lodged, and where the heat was strongest, there remained a black mark, which could not be removed by a much greater heat than that by which the sulphur was sublimed. The bulk of the air was not materially altered by this operation. A little blue paper being thrown up to the air after the operation, became green. Water absorbed about one-third of it, and acquired a strongly hepatic smell. The inflammable air was carefully washed, so as to separate from it all the hepatic air. I then mixed this inflammable air with dephlogisticated air, and inflamed them, expecting to find a greater quantity of phlogisticated air in the residue, than when the inflammable air was burnt, which had not been subjected to this process. But the difference of the residue does not exceed  $\frac{1}{3}$  the quantity of air decomposed in this manner, if we may judge from the following experiment.

Expe-

**Experiment.** Inflammable air, from which hepatic air had been made, and had been separated by exposure to water,  $4\frac{1}{2}$ , and dephlogisticated air  $6\frac{2}{3}$ , were inflamed in a large exploding jar. After the inflammation they measured 6; and after being agitated with lime water  $2\frac{1}{4}$ . This residue burnt with increased flame.

The airs used in this experiment were the same as those in the second experiment. The quantity of fixed air generated is only 0,035 less in proportion than was produced in the third experiment from the air in its original state.

The residue is only 0,17 more than it should be by calculation, allowing the dephlogisticated and inflammable airs to enter into fixed air in the proportion of seven to five.

The remaining heavy inflammable air is therefore very little altered as to its quality by this operation, though it is much less in quantity than can be accounted for from the production of hepatic air. For the light inflammable air in the constitution of hepatic air is expanded to the same degree as in its simple state; and an expansion might be expected, when the hepatic air is generated from the heavy inflammable, just as when the lighter air is separated from the heavy by the electrical shock; but no expansion is observed in this instance. I therefore suspect, that, when hepatic air is formed in the heavy inflammable air, the heavy air is imperfectly decomposed; that only a part of the light inflammable air is combined with sulphur; and that the remaining parts are precipitated in a state analogous to charcoal, and blacken the sulphur. Upon applying heat to the sulphur thus blackened, I have perceived an hepatic smell. This blackened sulphur is not entirely dissolved, like pure sulphur, by being boiled in caustic alkali, but a black powder remains. In one instance, this black substance dis-

peared after long boiling in strong nitrous acid. More experiments, than it is in my power to make at present, are necessary to determine fully the nature of it.

The analogy between the heavy inflammable air and charcoal is illustrated by the formation of hepatic air from charcoal and sulphur. These substances, heated in a small glass retort, yield hepatic air in great abundance. The blue vegetable colour is turned green by exposure to this air. After hepatic air had been generated for a long time from the same materials, without admitting any common air into the retort, ninety-nine parts in a hundred of the air which came over last were absorbed by water. The insoluble part appeared to be phlogisticated air. Thus sulphur and charcoal, heated in a glass retort, yield hepatic air, phlogisticated air, and volatile alkali, or a substance very analogous to it.

As far as I have been able to discover by experiments, the heavy inflammable air and charcoal consist of the same elements in different proportion. The application of heat to pure charcoal confirms this opinion; for the production of heavy inflammable air from charcoal, by mere heat, is constantly accompanied with a production also of phlogisticated air. I apprehend, that in these cases the charcoal is decomposed and resolved into these two parts. Whenever charcoal, or any substance containing it, is decomposed by heat only, the phlogisticated and heavy inflammable airs are produced; and when the heat is intense, Dr. HIGGINS has observed\*, that the air produced from these substances becomes rarer; as I imagine, in consequence of a portion of the heavy inflammable air itself being resolved by heat into its constituent parts. I would not lay much stress on the appearance of phlogisticated air from

\* HIGGINS on Acetous Acid, p. 293.

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the compound forms of vegetable, animal, and bituminous substances, all of which yield phlogisticated air and volatile alkali in great abundance; yet when the more simple modifications of the heavy inflammable air, as charcoal, vinegar, and, if Dr. PRIESTLEY is not mistaken, fixed air, give out phlogisticated air, when decomposed in close vessels, I cannot but infer, that phlogisticated air is an essential part of that peculiar substance which exists in all these states, whether that substance be called charcoal, or the gravitating matter of heavy inflammable air.

Hence it appears, that the phlogisticated and heavy inflammable airs combined, constitute charcoal; and that the mere application of heat always resolves charcoal into these two substances. But the heavy inflammable air is itself a compound of the lighter inflammable and phlogisticated airs. If phlogisticated air be combined with the heavy inflammable, or, which is the same thing, if light inflammable air be taken from it, charcoal is re-produced; therefore, when sulphur is melted in the heavy inflammable air, and hepatic air formed in it, the remaining parts of the heavy inflammable air return to the state of charcoal. And lastly, when sulphur is melted in contact with charcoal, the decomposition is complete; and the charcoal is resolved into its ultimate particles, the phlogisticated and light inflammable airs, with a small admixture of volatile alkali.

Thus far I have proceeded in the decomposition of the heavy inflammable air. The formation of this air, on many occasions, confirms what has been said concerning its analysis. In the resolution of compound bodies into their constituent parts, it may always be suspected, that the whole is not accounted for, that some part may have eluded observation, till the very parts

parts we assign are put together, and the same compound is produced from them. The frequent production of fixed air, from substances generally not supposed to contain the heavy inflammable air, has lately given rise to a new system in chemistry. The author of this system has the merit of pointing out the appearance of fixed air in almost all phlogistic processes, in the combustion of various substances, in the reduction of metals, and in the decomposition of acids; phænomena which cannot otherwise be accounted for, than by shewing that the specific matter of charcoal is a compound body; that its component parts are present in all these processes; and in some of them nothing else, if we except dephlogisticated air.

I have already taken notice of the formation of fixed air from nitrous ammoniac, which is now well known to contain nothing, but the phlogisticated, light inflammable, and dephlogisticated airs. This salt, heated in close vessels, yields dephlogisticated nitrous air in great abundance, mixed with a small proportion of fixed air. I have often repeated this experiment with nitrous ammoniac, which indicated no trace of fixed air either with lime water, or with acids, before its decomposition; but, when the salt was decomposed by heat, I always found lime water rendered turbid by the generated air; and, upon adding an acid to the turbid lime water, have observed air bubbles to be produced in it.

When the three elementary airs are in a condensed state, and are set free from any combinations, they unite and form fixed air without the assistance of heat. Thus fixed air is generally produced when metals are dissolved in the nitrous acid. In these solutions, the component parts of nitrous acid and the light inflammable air, being extricated at the same time, unite before they have acquired the aërisome state, and constitute fixed air.

Obje<sup>c</sup>ts

Objects are often too common or too near for our observation. Phlogisticated air presents itself in the decomposition of so many bodies, that its appearance excites no enquiry; and it is not regarded as essential to the chemical constitution of the bodies which yield it, excepting in the instances of nitrous acid and volatile alkali, two substances of very small extent in the scale of natural bodies. The calces of metals are well known to contain phlogisticated air; yet the effect of this air on calcination in general, and how far the very different calces of the same metal are influenced in colour or other properties by the different proportions of phlogisticated air, has never been considered. Fixed air is often formed from the calces of metals, mixed with water, or with some other substance containing light inflammable air.\* Red precipitate mixed with iron filings yielded very pure fixed air. Brass dust mixed with red precipitate, likewise gave out fixed air, though in less quantity. Turbith mineral and iron filings, treated in the same manner, afforded much less fixed air than the red precipitate and iron filings. It is probable, that the turbith mineral contains less phlogisticated air, than the red precipitate. The fixed air in all these experiments was mixed with phlogisticated and dephlogisticated air. Mr. KIRWAN † found, that the simple calx of mercury with iron filings and water produced fixed air. The same author also observed, that iron calcined with nitrous acid gave out, upon being heated, fixed air; and he found the production of this air renewed upon the addition of water. Dr. PRIESTLEY ‡ obtained fixed air from iron converted into rust by exposure to nitrous air. In all these experiments the

\* PRIESTLEY, VI. p. 253, 254.

† Essay on Phlogiston, p. 114.

‡ Ibid. p. 52.

three elementary airs are present, and, being expelled by heat from the metals with which they were combined, unite with each other, and form fixed air. It is not material to the present argument, whether the light inflammable air be supposed to be furnished from water, or from the regulus of a metal: it is enough for our purpose, that none of the substances employed in these experiments, contain heavy inflammable air or charcoal, in sufficient quantity to account for the fixed air produced, as Dr. PRIESTLEY \* has justly observed.

The growth of plants affords a strong proof of the formation of charcoal from the substances which have been assigned. If we may believe experiments, water and air alone are necessary to this natural process; yet vegetation is the great source of charcoal or heavy inflammable air. This enquiry is still in its infancy; but from the best experiments that have been made it should seem, that plants grow best in phlogisticated air; that they take in phlogisticated air, and give out dephlogisticated air. These phænomena cannot be accounted for but by supposing, that water is decomposed by growing plants; that part of its dephlogisticated air is discharged into the atmosphere; and that the other constituent part of water, with phlogisticated air, is taken into the growing substance. Thus the phlogisticated and light inflammable airs are brought together by the process of vegetation.

\* PRIESTLEY, VI. p. 319.

